CHAPTER 10

LAND FORMING FOR IRRIGATION

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Abstract. *Land forming for irrigation is a key part of the land improvement process in all regions where crop production is dependent upon irrigation. The state of the art of land forming as it relates to irrigation development, particularly surface irrigation, is presented. Topics addressed include system layout, soil survey and allowable cuts, topographic surveys, earthwork analyses, types of equipment, field operating procedures, cost and contracting, and safety. Computer-aided design, including various computer software packages, and extensive changes in equipment for land forming and its control emerging over the past 25 to 30 years are included.*

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10.1 INTRODUCTION

Land forming for irrigation is a key part of the land improvement process with the goal of sustaining high crop productivity. It provides a land surface ideal for surface irrigation and drainage. Both irrigation and drainage systems require land surfaces that transport water sufficiently slowly to allow adequate infiltration and minimize erosion, while at the same time transporting water rapidly and uniformly to prevent injury to plants. The benefits of land forming are extensive (Springer, 1966; Lyles, 1967; Quackenbush, 1967; Buras and Manor, 1970; Sewell, 1970; Harris, 1971; Kriz et al., 1973; Thomas and Cassel, 1979; Shih et al., 1981; and Shih, 1992) and include:

- improving surface drainage by eliminating low areas and adding grade to areas of no slope;
- permitting more efficient use of irrigation water and making possible the irrigation of a larger area with a limited water supply;

- improving efficient control of water by providing for uniform distribution;
- reducing the number of surface field ditches required for good drainage since each furrow carries its own water;
- reducing erosion by preventing water from concentrating in natural drainage ways;
- reducing herbicide and fertility losses because of better control of water;
- reducing ditch maintenance by minimizing the number of deep ditches;
- saving machinery-operating time in turning around at the end of large fields as compared to small fields;
- increasing the cropping area by removing ditches and fencerows;
- increasing machinery efficiency because point rows are eliminated and machinery can be operated at higher speeds;
- increasing the precision of inter-row tillage;
- increasing the accuracy of height or depth of the cutting edge of harvesting machines;
- reducing wear and damage to equipment working in the field;
- providing better crop and soil management because the uniform ground surface allows precision planting and fertilizer application, which results in more uniform germination and crop maturation;
- increasing crop yield because of better soil, water, and crop management;
- reducing organic soil subsidence by maintaining a more even water table depth within a field;
- reducing excessive organic soil mineralization and nitrification by eliminating the high spots; and
- saving energy in paddy rice production by reducing amount of water pumped for flooding the fields.

The benefits touch on all aspects of productivity. Further, the list addresses issues pertaining to all climatic regions, i.e., irrigated areas where production is dependent upon irrigation (arid, semi-arid regions) as well as areas where irrigation is supplemental to precipitation. In irrigated areas with higher precipitation, land forming is extremely important to control surface drainage and improves the uniformity of water application by surface irrigation. In some instances, the ideal land forming for surface drainage and surface irrigation systems have conflicting requirements: flatter slopes for surface irrigation systems generally result in higher irrigation efficiencies, but drainage may be inadequate.

Irrigation systems (whether surface, sprinkle, or micro) are selected and designed considering various factors applied to specific site conditions. These factors include:

- *water supply*—source location, delivery flow rate, quality, delivery schedule, delivery point;
- *crop characteristics*—effective root zone, growth characteristics, cultural practices;
- *soil features*—water-holding capacity, intake rate, depth;
- *topographic features*—surface irregularities, steepness, direction of slope;
- *geographic features*—field shape, natural drains, buildings, utilities or obstructions;
- *labor*—amount required, quality, quantity available, cost;
- *energy*—amount required and available, associated cost;

- *system cost*—hardware and other ancillary equipment, installation, operation, maintenance;
- *farm equipment*—type commonly used and/or available; and
- *farmer's preference.*

All irrigation methods may require some land forming to attain maximum production, depending mostly on the climatic region and irrigation method used. However, the performance of surface irrigation methods is impacted most by the field surface topography. To guide the process of land forming, topographic features influenced by the soil depth and type are paramount. Depending on the irrigation system selected, the field may be graded with a single or a series of slopes in the direction of irrigation, and either with or without *side fall*, i.e., field slope other than that in the direction of irrigation (discussed further in Section 10.2).

As used herein, *land forming* (or *shaping*) refers to both land grading and land smoothing. *Land grading* refers to the movement of soil associated with meeting the general slope requirements of the irrigation system design, while *land smoothing* (or *finishing*) generally refers to the removal of nonuniformities in that soil surface. The average finished slope is a statistical measure of how accurately the field was graded to meet the design slope. Land smoothing can be statistically described by the precision of the field elevations around the design slope (i.e., the standard deviation of the field elevations from the design slope).

Land grading and smoothing improve the distribution uniformity of irrigation water. This improved uniformity provides an opportunity to improve the irrigation application efficiency of the system. Generally, uniform irrigations improve the resultant crop yield, because of the potential negative impacts of low and high areas. Low areas are generally areas of over-application, resulting in poor soil aeration, associated oxygen deficiencies, and potential excess leaching of nutrients. High areas are generally areas of under-application, thus resulting in insufficient water to meet crop needs and leading to potential build-up of salts. Many times irrigators will apply additional irrigation water to sufficiently irrigate the high areas, which potentially exacerbates the negative impacts associated with the low areas and lowering the overall irrigation efficiency.

10.1.1 Scope

The objective of this chapter is to review the state of the art of land forming as it relates to irrigation development, particularly surface irrigation. Land forming associated with nonirrigated land is not addressed directly, although much of the information presented would apply. Topics addressed include system layout, soil survey and allowable cuts, topographic surveys, earthwork analyses, types of equipment, field operating procedures, cost and contracting, and safety. Computer-aided design, including various computer software packages, and extensive changes in equipment for land forming and its control have emerged in the past 25 to 30 years.

10.2 SYSTEM LAYOUT

Before the land forming for a field can be designed, the farm irrigation system, drainage system, main field boundaries, roads, and other physical features must be planned. From soil information, topography, method of water application, crops to be grown, and the farmer's own personal likes and dislikes, alternative field arrangements are developed. Field arrangement and design are important parts of the process of land forming. It is essential that planning be done with imagination. All of the practical potential layouts should be considered and the one best suited to the site selected.

The planner should consider and include, when appropriate, the following items when developing the irrigation system layout:

- location and elevation of the water supply;
- amount and arrangement of supply ditches and/or pipelines, as well as water control requirements;
- location, number, size, and elevation of drainage ditches;
- location, size and method of operation of the return-flow system;
- type of farm equipment to be used and ease of access to and operation within all fields for that equipment;
- field location and arrangement, to minimize soil variations within each field;
- combining small fields into larger fields, especially if larger farming equipment is to be used;
- minimizing non-cropped area;
- ease of management of irrigation water and cultural operations; and
- current and future crops to be grown.

Design criteria must be established before the field can be subdivided and the design for land forming prepared. Both irrigation and drainage affect the allowable length of fields. Excessively long fields may create erosion problems during irrigation and/or rainfall. Short fields require more delivery and drainage facilities for a given area. Efficiency of machinery operation depends on the type of machinery used, but generally increases with length of field.

Distribution uniformity (DU), when used as the design criterion for surface irrigation systems, can be described as

$$DU = \mathrm{f}\,(I, n, s_o, L, Q_{in}, Z_n) \tag{10.1}$$

where I = infiltration characteristic, generally defined by a relationship between cumulative infiltrated depth and infiltration opportunity time

n = flow resistance (Manning n)

s_o = slope (or series of slopes) in the direction of irrigation of the area to be irrigated

L = length of the furrow or border

q_{in} = unit flow rate, i.e., flow rate per unit width (Q_{in}/W) or flow rate per furrow (Q_{in} is the inflow rate to the field, and W is the width of the area being irrigated in a particular set)

Z_n = net depth to apply.

Infiltration and flow resistance are characteristics inherent to the irrigation site. At the time of design, the other four factors (slope, length, unit flow rate, and net depth to apply) are adjusted within various constraints to provide an irrigation system that will meet the targeted design performance criteria. The design slope in Equation 10.1 reflects land grading requirements. In the U.S., irrigation and drainage guidance for the particular type of surface irrigation system(s) being considered, i.e., how the last four factors of Equation 10.1 are combined, can be obtained from various sources such as the USDA-Natural Resources Conservation Service (formerly USDA-Soil Conservation Service), Cooperative Extension Service, universities, USDA-Agricultural Research Service, or private consultants. These design guidelines, when combined with soils, depth of water to apply, and flow information, provide optimum field slopes and lengths to achieve the targeted design criteria. Additional information on surface hydraulics is given in Chapter 13 and design procedures are given in Chapter 14.

10.3 SOIL SURVEY AND ALLOWABLE CUTS

Land forming should only be done after first knowing the soil profile conditions and the maximum cut that can be made without permanently affecting agricultural production by exposing infertile and/or rapidly draining subsoils. General soil survey maps are available for many areas and, if not available, the services of a soil scientist should be obtained. In the U.S., soils information may be obtained from the local Natural Resources Conservation Service (NRCS) office, local Cooperative Extension Service, or a state university. The standard soil survey generally delineates areas larger than 2 ha. The soil profiles are described to a depth of 1.5 m. In alluvial soils, sand and gravel pockets may occur within a soil-mapping unit of some other soil type. A detailed site investigation should be made to determine the extent of such material before the land grading begins so that adequate fill material can be made available. Sand and gravel pockets that occur near the water inlet end of a surface irrigation system may greatly limit the irrigation efficiency because of high intake rates. It is often advisable to remove these sand and gravel materials and replace them with soil similar to the rest of the field. If there are doubts as to the soil depths, investigation with an auger in several representative locations within the land area is mandatory.

Soils with deep, well-drained subsoil generally have few limitations on depth of cut. Some shallow soils may be suitable for irrigation, but may not have sufficient depth (e.g., shallow soils over bedrock, gravels, caliche, heavy claypan, or fragipans) to permit the necessary land forming needed for surface irrigation, while they could be successfully irrigated with sprinkle or microirrigation systems. Cross-slope benching is sometimes used on sloping land to reduce the depth of cut needed to obtain suitable field grade and can reduce the cost of land forming (Dedrick, 1989).

10.4 TOPOGRAPHIC SURVEY

It is extremely important that the entire farm be studied before any grading work is attempted, even though land grading is usually done on a field-by-field basis, because the most economical design for an individual field may be undesirable when the entire farm system is considered. The factors noted in Section 10.2 should be considered by the designer in planning the overall farm development. A general topographic map of the entire farm showing the location of all physical features can provide much of this information. The designer must select the irrigation layout; the most desirable location for the various elements of the farm irrigation, water reuse, and drainage systems; and location of field boundaries and field roads. By presenting this type of information, several alternative designs can be developed for consideration and selection by the farmer or farm manager. The selected plan should permit land grading to be carried out on individual fields, even over a period of years, if necessary.

Planning is aided by development of a detailed topographic map. When collecting data for the map, consider:

- What is the size of the area to be planned?
- What are the availability and capability of personnel?
- What are the time constraints for getting the job done?
- How will the topographic data be analyzed, i.e., how will field slopes, earthwork quantities, and haul distances be calculated?
- Does the type of grading and smoothing equipment and the procedure used during the grading and smoothing operations dictate a certain topographic layout?
- Will grid stakes be required for the grading operation?

- What type of surveying equipment will be used to collect the data?
- How will the topographic map be generated, by hand or by computer?

In simplest terms, the topographic data collected includes the elevation, z, of variously located x and y coordinates, including boundaries to the area. The survey data collected in the field will be structured either according to a uniformly spaced, grid-based pattern or irregular spacing based on documenting the extremes and changes of the surface. The choice of data collection pattern will depend on the general smoothness of the area, the method to be used to analyze the data, type of grading equipment to be used and associated design required, and how the field surfaces will be mapped.

Highly accurate global positioning systems (GPS) have been introduced to the land forming industry during the past 10 to 15 years. In one system, the elevation information is obtained from a laser transmitter/receiver system and the x-y coordinates from the GPS. A second system gets both the position and elevation from the GPS. Both systems can be used with either grid-based data collection or irregularly spaced patterns.

10.4.1 Grid-Based Pattern

10.4.1.1 General description. The grid-based pattern is best suited to areas that are relatively smooth. If, during construction, the method of grading is to be based on lanes and controlled by periodic cut/fill stakes, a grid layout has the advantage of defining the lanes. If the method of grading depends on manual control, grid locations must be preserved until construction when these same locations will be used for the cut/fill stakes. If laser-controlled scrapers are used for grading, only a few points of known elevation are required and systematically located cut/fill stakes are not needed. Information needed regarding the finished slope will depend on the type of laser hardware used. The main disadvantage of the grid pattern is that critical high and low points and changes in slope do not often occur at grid points, and thus they are missed in data collection and analyses leading to inaccurate surface portrayal.

For ease in computing volume and area, especially when not computer aided, the grids should be made square; however, stakes may be set at any spacing desired by the designer. The most commonly used spacing is 30 m. Larger spacing makes it more difficult for the operator of manually controlled grading equipment to maintain the grade from one stake to the next. Closer spacing greatly increases the work of staking, surveying, and computing the grading design. Occasionally, it may be necessary to locate additional points in the grid pattern to record significant topographic changes in the land surface or to show irregularly shaped boundaries. If closer spacing or numerous additional points are needed to describe the topography, irregularly spaced data collection may be more appropriate.

Grid-based elevation readings are either taken in the center of each square or at the corners. Each data set type requires a different method of analysis. An elevation reading taken in the center of each square is assumed to represent the mean elevation of that entire square. The field surface analysis resembles a checkerboard with each square at a different elevation. Exact elevations around the border of the surface are unknown and either must be estimated or can be defined by adding readings at a few locations. The field layout is simple, usually adequate for flat, uniform surfaces, and lends itself readily to simplified approximations with regard to slope design and earthwork calculations.

When the elevation readings are taken at the edges of the squares, a more accurate surface analysis model (based on triangulation) is possible since each square actually defines two triangles. This type of grid data can be reduced to the first type of grid representation if one of the simple approximation methods is to be used for design of land forming.

10.4.1.2 Staking the field. Wood laths (10 mm × 45 mm × 1.2 m) are excellent stakes for setting the grid points. They are easily set by the technician from a standing position, and cut or fill markings near the top of the lath are easily seen by the equipment operator. The laths should be sharpened and driven into the ground far enough so that they will remain standing until the grading work is completed.

A procedure is outlined by Anderson et al. (1980) to guide the complete staking of a field. The procedure entails the establishment of key rows of stakes across the ends of the field from which the remaining grid stakes can be set by eye. For larger fields it may be desirable to establish the guide rows near the center of the field to eliminate some of the errors that occur in setting long lines by visual sighting.

10.4.1.3 Survey equipment and techniques. Since the x-y coordinates are defined by the grid layout, the elevation is the only remaining unknown. The elevations are usually determined with an engineering level and rod or a rod with a laser receiver. To facilitate field readings, the rodman may use an all-terrain vehicle or pickup truck to move quickly from reading site to reading site. In some cases, the laser-control equipment attached to the tractor-scraper unit is used.

10.4.2 Irregularly Spaced Pattern

10.4.2.1 General description. Irregularly spaced patterns can be used to document the field surface. Irregularly spaced data points are useful in mapping the area to be irrigated as well as to map important planning features outside the irrigated area. No prior layout is required. The location of data points is selected in the field and should reflect various controlling features or break lines. *Break lines* are topographic features that have more or less uniform slope, such as natural and man-made surface drains, streams, lakeshores, roads, railroads, ditches, and ridgelines. Numerous data points can be used to adequately represent any feature. On uniform portions of the ground surface, the distance between readings can be increased without compromising the integrity of the data analysis model.

10.4.2.2 Surveying equipment and techniques. Analyses of irregularly spaced data can result from any surveying technique that provides both the location (x-y coordinates) and the associated elevation readings. Typical equipment used includes the transit, plane table and alidade, automated total station, aerial photographs with stereo mapping, and laser-GPS and GPS surveying systems. If accurate and detailed contour maps for the area already exist, electronic digitization can be used to develop a database for reproducing the topographical map and for calculation of land grading .

Transit. The transit provides both location and elevation. The surveyor uses the stadia readings to determine distance from the instrument and, with the horizontal and vertical angles, to calculate the coordinates of a point. Electronic distance measuring equipment (EDM) can be used instead of the stadia. EDM is rapid and eliminates some hand calculations and associated errors, especially when combined with handheld, battery-powered electronic notebooks or data loggers to register and store data, thereby reducing the need for hand recording all survey records.

Plane table and alidade. The plane table and associated alidade are best suited for situations where the contour map itself is the end product. The method is of limited use where data are needed for land grading design. Often, an engineering level is used with the plane table and alidade to supplement the data collection by determining the data point elevations. The alidade is used to sight the rod. Stadia crosshair readings are used to determine the distance to the sighted point. The rectangular base (also a ruler or scale) of the alidade rests directly on the map as it is drawn. The line of sight and the scaled horizontal distance to the rod are plotted by hand to locate the x-y coordinates of each data point as the field is being surveyed. Location of the point replaces the recording of the horizontal angle.

The plane table and alidade can be used to develop contour lines directly by fixing a target on the rod at a height that will result in the elevation of a desired contour line. A series of irregularly spaced points, found to be at the desired elevation using the level, are located and drawn on the map with the alidade. Connecting the points draws the contour lines.

Total station. A popular, current surveying technique involves the use of the automatic total station. This apparatus is a battery-powered, computerized transit using EDM technology that also performs various data calculation, recording, and transfer functions. The total station electronically registers the x-y distances and elevations of points selected by a rodman carrying a mirror-like prism. The instrument operator transmits a beam of light to the prism enabling the instrument to measure horizontal and vertical angles (like a transit) and the distance from the instrument to the target. The 3D coordinates of each selected ground location are electronically calculated and stored, later to be transferred for data analysis. It is often possible to survey a very large area from a single location since such equipment functions accurately over long distances, with actual distance depending on atmospheric conditions.

Aerial mapping. Aerial photography with stereo plotting is best used when a large area (several thousand hectares) is to be planned as a unit or where work is to take place on several large adjacent farms at the same time. The photography should be done during the season of low vegetative growth and the maps plotted, as they are needed. This procedure requires that vertical and horizontal control points be established before the photos are taken. These points, which must be visible on the photos, usually are made with white plastic strips in the form of a cross. Low-level photographs are taken from an airplane. The height of the plane above ground level will depend on the camera used and the detail required for the topographic map. For example, a 150-mm focal length lens in the camera at about 900 m to 1200 m above the ground will provide the resolution needed to plot 0.6-m contour lines. The topographic map is made with a stereoscopic plotter using stereo pairs of photos. While excellent for general planning purposes, the individual areas to be graded will require additional surveying to provide accurate data for grading design calculations.

Laser-GPS system. This system combines the use of laser and GPS technology to provide survey information similar to that provided by the total station. In addition, such surveying systems are coupled with computer-aided land leveling software that produces various design and display information that is used directly with land forming equipment and/or as support material for the equipment operator.

GPS surveying system. This recently introduced system performs all of the functions of a total station utilizing the GPS to obtain both the field coordinates and the elevation.

10.4.2.3 Digitization. Digitizing provides a means of transforming a contour map from any source (including plane table and alidade data) into a database for analysis.

This can be done either manually or using a digitizer. If done manually, either a grid is established prior to the survey so that the x-y coordinates are known, or the contour map of the area to be irrigated is drawn using irregular survey points as needed. A clear plastic overlay, marked with grid locations, is superimposed on the map enabling the elevations to be interpolated. Digitizing technology registers the location of each x-y coordinate of interest from maps or data points. The elevation is entered either by defining a series of x-y coordinates on a contour line or by entering individual elevations for the selected points. When using digitized contour lines in surface computations, the user needs to insure that points on one contour line triangulate with those of an *adjacent* contour. Computer software exists that allows such user intervention. Further, the user must prevent three points on the same contour from forming a triangle, which would then erroneously form a level triangle.

10.4.3 Digital Elevation Models (DEMs)

The availability of computers with the capability to rapidly process large quantities of data has made hand or calculator analyses almost obsolete. The same skills once used to carefully draw maps and make various earthwork calculations are now applied toward managing inexpensive computer software to rapidly produce, revise, and refine contour maps and system design options. The digital representation of the topographic survey data, i.e., an array of points whose horizontal positions are given by their x and y coordinates and whose elevations are given as z coordinates, are known as *digital elevation models (DEMs)* or *digital terrain models (DTMs)*. Generally, when an irregularly spaced DEM is utilized, a *triangulated irregular network (TIN)* surface model of the area is formed. The TIN model is constructed by connecting points in the array to create a network of adjoining triangles. (The same procedure can be applied to grid-based data.) Each of the triangles is formed by lines joining together three of the actual survey points, one at each corner of the triangle. Creation of a network of "near-equilateral" triangles is a criteria commonly used in the development of TIN models. Further, the TIN depends on proper identification of break lines. Break lines must be identified to the computer in the input array. Once the break lines are appropriately identified, the break lines become sides of triangles in the network of triangles created when developing the TIN model. Information from this network of triangles can then be used in all subsequent data analysis and display.

10.4.4 Automated Contouring Systems

Available contouring software allows a topographic map to be drawn by technicians with no experience with hand-drawn contours. Automated contouring systems generally make two assumptions concerning TIN models: (1) each triangle side has a constant slope, and (2) the surface area of any triangle is a plane. Based on these assumptions, elevations of contour crossings are interpolated along triangle edges. After review of the initial contour map, the user may modify any portion of the resulting triangulation as needed, and thereby insure that the surface model accurately simulates the actual ground surface. Although the contouring program forms the surface model automatically, most programs incorporate some means by which the user designates the boundary of the surface to be mapped. In some cases, the boundary is assumed by the program and can be altered if it is incorrect.

Various mathematical techniques are used to approximate field contours. Data interpolation is a common technique that involves interpolation between adjacent grid points to determine the coordinates of any contour line that may pass between the points. Without smoothing, however, this method may produce erratic values and contours that are difficult to interpret. Polynomial regression has been used (Portier and Shih, 1982) to estimate parameters for a mathematical model that produces a smooth, continuous surface with well-behaved contours. A disadvantage is that none of the original observations are likely to be found on the fitted surface, however, this may not be a problem if the goal of the analysis is to obtain a general impression of the field for making decisions.

The software utilized for developing topographic maps generally consists of a data editing program, a contouring program, and a computer-aided design (CAD) program. Within the data-editing program, the data are screened to exclude points such as benchmarks and other references that are not on the field surface. A 3D model of the ground surface is formed within the contouring program. From this model the contour map is then drawn according to the interval selected by the user. Usually, topographic maps with contour lines using 0.3-m intervals are adequate for description and design. On very flat or irregular topography, 0.15-m increments may be desirable. When the slope exceeds 1%, the planner may desire a contour interval of 0.6 m or greater to have a more readable map. Contouring software is available that enables designers to produce 3D views of the present (existing) terrain and as it will appear after the proposed modification. These views can be extremely helpful in assisting landowners and/or project officials to visualize, and assess, the various development alternatives.

The contour map can be output to a computer printer, a plotter, and/or a CAD program. It is important that the topographic map illustrates other physical features of the farm. Usually within a separate CAD program, the designer combines the contour map with other data that show the location and elevation of benchmarks, location and source of irrigation water, existing field boundaries, drainage patterns and outlets, farmstead, farm roads, location of both buried and aboveground utilities, and any other physical features that may affect the planning of the system and the design of the land grading for each field.

10.5 EARTHWORK ANALYSES

Design and analysis for land forming include processes for defining the finished field surface, adjusting for cut and fills to compensate for shrinkage of the soil, and making the necessary earthwork calculations. At the present time, computers are used nearly exclusively to optimize cuts and fills. Powerful, easy to use, and relatively inexpensive software for land forming design is commercially available from vendors of surveying software. Many consulting engineering firms, federal agencies, and state universities involved in irrigation development have such programs. Most commercial software is able to handle irregular field shapes, irregularly spaced data, and other complex design situations. Cut-fill maps and an analysis of the work and haul patterns required to achieve the design are important options now available. The following discussion is intended to provide an overview of design procedures commonly used in design and analysis of land forming, supplemented with an ample number of references. A limited number of computational equations are given to provide examples of how certain issues are addressed. In most instances, numerous procedures are available for solving various aspects of the earthwork analysis process; it is left to the interested readers to decide which procedures best accommodate their needs.

10.5.1 Defining the Finished Field Surface

As noted earlier, the survey data collected can be according to either a grid-based or irregular pattern. Generally, a mathematical description of the design surface is developed that meets the functional requirements of the land forming operation. An equation for a linear plane is used to describe the linear land-grading plane where the elevation, *H(x,y)*, at any point *(x,y)* is given by

$$H(x,y) = a + bx + cy \tag{10.2}$$

where a is the elevation of the plane at the origin of the x and y coordinate system, and b and c are the two edge slopes of the plane in the x and y directions, respectively.

The best-fit linear plane can be determined by linear regression analysis techniques. Best-fit approaches are useful, especially, for drainage purposes and when the slopes, b and c in Equation 10.2, are within tolerances for the irrigation system. In many surface irrigation design situations, the design plane will differ from the best-fit plane (e.g., the design plane generally has two fixed design specifications which leaves only one dimension in which the plane can be changed to balance cut and fill volumes). For example, in border irrigation there normally is no cross slope in the border strips and the field elevation at the inlet may be fixed. This means that the plane has only one factor, the longitudinal slope, which can be varied in the design. Level basins, where the basins are designed to be level in both directions (Erie and Dedrick, 1979; also see Chapter 14), are another example. In this case, elevation is the only factor that can be varied for land grading. To minimize earthwork volumes, iterative adjustment of the slope or elevation of the design plane within prescribed limits is done by many earthwork software packages.

Numerous procedures for defining the finished field surface have been based on uniformly spaced, grid-based patterns. In this work, much of the land grading design has involved determining a linear plane that balances cut and fill volumes to minimize earthwork. Further, design procedures for nonlinear surfaces have been presented (Hamad and Ali, 1990; Ebne-Jalal, 2004). The following paragraphs provide an overview of some of the linear plane procedures developed for analyzing grid-based data. Note that the focus is on minimizing the earthwork requirement.

Givan (1940) introduced the first systematic procedure to perform land-grading designs for rectangular fields. Givan used least squares procedures to define a plane surface that fits the natural ground surface with a minimum of earthwork. Chugg (1947) developed the first land grading design method for irregularly shaped fields. He applied the least squares method to calculate the best-fit slope, using transparent and coordinate papers to simplify and organize the computational process. The procedure requires the graphical determination of rectangular distances from the origin to the centroid and a separate determination of the centroid elevation.

Raju (1960) developed a method to calculate the slopes of the graded plane, which he called the *fixed volume center* method. His method is based on the criterion that the total volume of earth and the center of volume will be the same before and after grading. This assumption is required to ensure a balance between cut and fill and to obtain the least amount of grading and movement of earth. The fixed volume center method has proven to be an accurate method of land grading, and although time consuming when done by hand, can readily be used with computers.

Harris et al. (1966) introduced what they called the *best-fit warped surface*, in which they recognized the need for other types of design by suggesting that a field-surface shape that allows row and cross-row grades to vary within prescribed limits would be useful, especially when surface drainage was needed. Such a surface has variable slope in the irrigation direction, while the cross slope follows the natural ground profile with minor modifications. Design limits are maximum and minimum row grades and cross slopes, maximum change in row grade and cross slope at a station, and the cut-fill ratio.

Shih and Kriz (1971) presented the *symmetrical residuals* method of land grading design for both rectangular and irregularly shaped fields. The method is based on residual properties, Newton's divided-difference interpolation procedure, and statistical properties of the best design with an unbiased estimate and minimum variance. Sowell et al. (1973) applied linear programming techniques to the land-grading designs presented by Shih and Kriz (1971) and found that the linear programming technique gave a smaller total sum of depth of cut.

Paul (1973) developed two methods to calculate the slopes of the best-fit plane, the *double-centroid* and the *computer-minimized cost* methods. Hamad (1981) proposed a method for quick estimation of the volumes of earthwork by using probability theory. Manela (1983) applied the least squares method to find the best-fit plane. Scalloppi and Willardson (1986) further developed a practical procedure to calculate the slopes of a graded plane using the least squares method.

All of the above design methods involved trial and error procedures to determine the plane that balances cut and fill volumes, considering the shrinkage of the soil, to minimize earthwork. Easa (1989) presented formulas for direct land-grading design that eliminates the need for trial and error procedures to minimize earthwork. The method explicitly considers the required design specifications, which may include the two edge slopes of the plane, one edge slope and a control point, or two control points. Such an approach is important in many practical situations in the field where many times the finished plane must conform to certain boundary conditions.

Procedures also have been developed for analyzing irregularly spaced data. The best-fit design plane generally can be generated by a modified least-squares technique in which each data point is weighted in the analysis in proportion to the area it represents.

10.5.2 Computation of Cut and Fill Adjustments

In land shaping it is essential that the volume of material excavated be adequate to make the fills. If the cuts equal the fills without borrowing or wasting material, the earthwork is in balance. Experience has shown that the volume of cuts computed from the design must exceed the fills within a certain percent. The cut-fill volume ratio, R, is defined as

$$R = \frac{C'}{F'} \tag{10.3}$$

where C' and F' are the cut and fill volumes, respectively, after the parameters of the plane have been adjusted.

Cut-fill ratios generally range from 1.2 to 1.6, but can be as low as 1.1 and as high as 2.0 (Michael, 1978). The cut-fill ratio depends on factors such as soil type and its moisture content, both of which generally vary with depth of cut; the earthmoving equipment weight, its tire size, and number of passes made over the soil; and the depth of the layer (commonly referenced as "lift") of soil deposited with each pass of the equipment. All of these factors influence the extent of compaction. The correct estimation of the cut-fill ratio is an important factor in the earthwork design. Shih (1992) provided a generalized guide for selecting cut-fill ratios dependent upon soil texture, depth of cut and fill, organic matter content of soil, and roughness of the soil surface (Table 10.1). Generally, it is best to base this estimate upon the judgment of those having local experience with the soils in question. For large projects, it may be appropriate to use a portion of the area as a test of the cut-fill ratio to be able to adjust the earthwork design for the remainder.

The best-fit linear plane (Equation 10.2) assumes that the cut and fill volumes are equal. This formula for the best-fit plane can be used directly if the shrinkage of the soil during leveling is negligible. However, under most conditions, to obtain the desired cut-fill ratio (Equation 10.3) the parameters, *a*, *b*, and *c*, of the design land grading plane (Equation 10.2) must be adjusted. Clearly, the adjustments of the parameters of the land-grading plane should have the effect of lowering the plane. Most adjustment procedures have focused on lowering the plane, i.e., reducing *a* in Equation 10.2 by some amount, Δa, where $\Delta a = a - a'$ and a' is the elevation of the adjusted plane:

$$\Delta a = \frac{1+R}{2RN_t}(R\sum F - \sum C) \tag{10.4}$$

where Δa = increment the grade line is lowered, m
R = cut-fill ratio
N_t = number of both cut and fills coordinates
ΣC = summation of cuts before lowering the plane, m
ΣF = summation of fills before lowering the plane, m.

A trial and error procedure generally is used to adjust *a*, *b*, and *c* to satisfy *R* in Equation 10.3. As noted earlier, Easa (1989) developed approximate adjustment formulas for all design parameters *a*, *b*, and *c* that can be applied directly to determine the position of the plane that satisfies the cut-fill ratio. Approximation formulas like those presented by Easa (1989) are essential when calculations are being done manually and can be a useful tool within computer programs. Since R is simply an estimate based on experience, the adequacy of the cut-fill ratio should be checked as the land shaping progresses.

Sometimes it is necessary to use material from the field to construct farm roads or elevated ditches, or material excavated from a drain may need to be spread on the field. The adjustment in the plane to allow for this material can be estimated by the following equation:

$$\Delta a' = K\,\frac{V}{A} \tag{10.5}$$

where $\Delta a'$ = increment the grade line is lowered, m
V = volume of compacted fill in a road or elevated ditch to be taken ("borrowed") from the graded surface, or the volume of soil to be distributed ("wasted") over the graded surface when in its compacted state, m^3
A = area of the field, m^2
K = dimensional constant equal to 1.0 for $\Delta a'$ in meters.

Table 10.1. General guidelines for selecting cut-fill ratios for land grading design (Shih, 1992).

Cut-Fill Ratio	Soil Texture	Depth of Cut and Fill	Organic Matter	Roughness of Field Surface
Low, 1.10–1.25	coarse	deep	low	smooth
Medium, 1.25–1.40	medium	moderate	medium	moderately smooth
High, 1.40–1.70	fine	shallow	high	rough

10.5.3 Earthwork Calculations

The designer of the land grading program must be concerned with minimizing the land grading costs while carefully considering the layout of the system, the irrigation efficiency attainable, labor requirements, cost of operation and maintenance, and farmability. Thus, the optimum or minimum cost of land forming will be the minimum cost associated with meeting the above criteria. The volume of excavation, or cut, is generally used as a basis for contracting and for estimating equipment requirements and job schedule. Various procedures have been developed to minimize cuts and fills. In most instances, minimizing cuts and fills does not minimize costs (flat, uniform fields being an exception). The goal is to minimize the amount of work that must be done which includes minimizing the volume of cut and haul distance. Type of equipment also can affect the costs of land forming. In some instances, a distance criterion such as average haul distance is used to supplement the purely volumetric method generally used. The following paragraphs discuss some of the commonly used methods for computing volume of cut or fill. They all represent ways to calculate the volumetric difference between two surface models, one being the existing or original surface and the second representing the proposed design surface.

The *summation* method, the least accurate of the methods presented, is used to provide quick estimates of volumes to be excavated (USDA-SCS, 1961). The method assumes that a given cut or fill at a grid point represents an area midway to the next grid point. The grid point is considered as being in the center of the grid rather than at the corner. The product of the cut in meters and the area of the grid in square meters provide the required excavation volume in cubic meters.

Where excavation involves the entire grid, the volume of earthwork could be obtained by multiplying the area of the grid by the average cut at the four corners of the grid. Since cut and fill both often occur within a grid, a procedure known as the *four-point* method is used. This method is based on the equations

$$V_c = \frac{L^2}{K}\frac{(\sum C)^2}{\sum C + \sum F} \tag{10.6}$$

$$V_f = \frac{L^2}{K}\frac{(\sum F)^2}{\sum C + \sum F} \tag{10.7}$$

where V_c = volume of cut, m^3
V_f = volume of fill, m^3
ΣC =sum of cuts on the four corners on a grid square, m
ΣF = sum of fills on the four corners of a grid square, m
L = length of the grid square, m
K = dimensional constant equal to 4 when C, F, and L in m and V in m^3.

An accurate method of computing the volume of cut or fill in land forming makes use of the prismoidal formula,

$$V = \frac{L}{6}(A_1 + 4A_m + A_2) \tag{10.8}$$

where V = volume, m^3
L = distance between end planes, m
A_1 and A_2 = end plane areas, m^2
A_m = middle section plane area, m^2.

This formula is easily adapted to computer applications, but it is laborious by hand or calculator.

Many currently used computer-aided land forming programs determine the soil volume through the use of a *triangulated irregular network* (TIN) of elevation differences between the original and design surfaces (digital terrain model, DTM) to generate tetrahedrons from which volume can be calculated. The tetrahedron is used since it is the simplest enclosed figure that can be made from the least number of planes. By representing the original surface by its survey locations, it preserves the exact elevations as surveyed. The procedure includes the following steps:

1. Calculate the difference in elevation between the existing ground DTM and the proposed design surface DTM for all key points. Key points might include all data points on the existing ground model, defining data points for the design surface (e.g., corners of the area to be graded), and various intermediate points that may be formed by the intersection of triangle sides between the two DTMs. The calculation is done by projecting each point onto the other surface, interpolating the corresponding elevation, and calculating the difference.

2. A TIN is generated to represent the DTM created by the elevation differences. The triangles for the elevation difference TIN are generated honoring all break lines (e.g., elevations along a ridge and/or along the bottom of a drainage way) and points common to both DTM surfaces.

3. The TIN is used to determine volumes by breaking the data for each triangle into the appropriate number of tetrahedrons. The volume of each tetrahedron is calculated and the volumes are added together to compute the cut and fill volumes between the original and the design DTMs.

4. A form of the prismoidal formula (Equation 10.8) is used to calculate the volume of the tetrahedrons. Various solution procedures are used within the earthwork software packages to apply the formula. Most procedures are proprietary.

10.6 TYPES OF EQUIPMENT

There is a great variety of equipment that can be used for land forming. In some instances, machinery has been made more efficient, more reliable, more compact, and can move more soil than formerly. Each type of machine has its own capabilities and limitations. Over the past 25 to 30 years, laser-control technology has been adapted to

Figure 10.1. GPS-based leveling systems use signals from satellites to control a scraper or scrapers as they move through a field, shown graphically on the left. The system is anchored in the field by a base station reference (right). A display, control unit, and GPS antenna are mounted on the tractor.

most tools used in land forming; and a class of scrapers that can both carry, and in some instances, precisely smooth the design surface has been developed. As noted in Section 10.4, highly accurate global positioning systems have been introduced in the industry of land forming, and more recently have been adapted to its tools (Figure 10.1). These technologies have significantly impacted the choice of equipment and how it is used. The examples of equipment described in this section were selected to illustrate some of the types that are being used (Gattis et al., 1959; Haynes, 1966; Fisher et al., 1973; Shih, 1992; Wiedemann et al., 1977; Dedrick et al., 1982). All equipment for land forming must be kept in good repair. The best type and size depends on the particular job.

10.6.1 Power Units

Prior to the 1960s, crawler tractors were used to pull most scrapers. Crawler tractors are still used in special circumstances since they have low soil compaction characteristics, provide excellent traction on a variety of soils, and can move large volumes of earth when used with 6- to 15-m^3 carrier-type scrapers. They are well suited for short hauls but their slow speed (about 8 km/h) limits their suitability for broad use.

Most of the land forming is now being done with either self-propelled rubber tired scrapers or scrapers pulled with rubber-tired wheel tractors. Their high field speeds and maneuverability makes them well suited for this type of work. Two-wheel units are more maneuverable than four-wheel units. Either can be used with scrapers to great advantage on land-grading jobs requiring long-distance hauling. They need to be appropriately matched to the earth-moving equipment as certain combinations are better than others.

Bulldozers are suitable for making heavy cuts and moving earth a short distance. Earth moving distances by bulldozer should not exceed 90 m, but less than 60 m is preferred. Bulldozers are well-suited for certain rough grading work and are essential as pusher tractors when extra power is required for loading large scrapers.

10.6.2 Equipment for Land Grading

Most land grading where large quantities of earth are to be moved over appreciable distances is done with earth-moving scrapers ranging in capacity from about 1.5 m^3 to 20 m^3. The advent of the fixed-blade scraper has made it much easier to control depths of cut and fill allowing much larger-volume scrapers to be pulled by smaller power units (e.g., farm tractors).

Motor graders and blade-type graders pulled by tractors may be used for land forming on small fields, especially for narrow benches or where only minor grading work is needed. They are used more extensively for shaping ridges on the downhill side of benches and the slope from one bench to another; excavating relatively small channels, such as shallow drainage ditches, where the excavated material can be spread or shaped along one or both sides of the channels; constructing divisions between irrigated borders or basins and crowning land; and maintaining shallow drainage ditches or field laterals.

Many types of scrapers can be, and generally are, equipped with laser and/or GPS control systems. The laser technology was originally applied in agriculture for automatic grade control for subsurface drainage equipment (Fouss et al., 1964) and was later adapted to equipment used in land forming. Development of highly precise GPS technology over the past 10 years has facilitated its use with such equipment. Laser and GPS precision-guidance systems have revolutionized the process of land forming.

The carrier-type scraper is a tractor-drawn implement that excavates, loads, hauls, and spreads earth. It consists of a bucket mounted on rubber-tired wheels with a blade and apron across its front end for cutting, scooping and retaining a load of earth. Carrier-type scrapers can be used efficiently on many land-grading jobs and are most efficient where the depth of cut is sufficient for rapid loading. The scraper must be pulled by the right size and type of tractor. Often, on large earth-moving jobs, these scrapers are operated in groups with a pusher tractor. Carrier-type scraper sizes range from 2 to 20 m^3 capacity with the smaller capacity being designed for use with farm tractors.

Elevating scrapers are used for land grading, especially where intermediate depths of cut are required. Farm tractors commonly used with four-row equipment can handle the 4-m^3 size. Large farm tractors or contractor-type tractors are used to pull the larger scrapers. A very desirable feature is the ability of the elevating scraper to load under most depths of cut and soil textures. In addition, cutting and spreading can be done evenly.

The ejector scraper, a relatively recent addition to the land grading and smoothing industry, is a fixed-blade scraper that can be used in place of the elevating scraper in some instances and is exceptionally useful where relatively small cuts are required (Figure 10.2). Ejector scrapers range in capacity from a few cubic meters to more than 10 m^3 and can be used singly or in tandem. The back wall of the bucket is moveable. Soil is forced or ejected out of the scraper when hydraulic cylinders push the back wall forward. The soil flows out of the scraper at an even rate, simplifying the grading operation. Further, the cutting edge can be precisely positioned with laser-control equipment resulting in precisely finished grades. The moveable back wall of the ejector scraper can be fixed in a forward position to create a land-smoothing device similar to the bottomless drag scraper discussed below. Thus, the scraper is a tool that can be used to cut, haul, and fill over relatively large distances while also being used to provide the final smoothing operation.

10.6.3 Equipment for Land Smoothing

Normally, it is impractical and too expensive to finish land surfaces to exact grade with heavy earth-moving machines. The heavy scraper work should provide a field surface such that two or three passes over the field with land smoothing equipment, designed to remove small grade irregularities, will produce the desired uniform surface.

10.6.3.1 Bottomless scrapers. The bucket or bowl of a bottomless scraper has little or no bottom and earth moving is accomplished by scraping soil from areas that are above grade, dragging it a short distance, and depositing it in areas that are below grade. Bottomless scrapers work best in a loose soil that has adequate moisture so that a smooth, relatively firm surface remains after the smoothing is completed. Dry, powdery soil conditions should be avoided. The field should be watered when such conditions exist, then when the field has sufficiently dried, the surface is worked with a disk or shallow chisel before the final smoothing is done.

There are two basic types of bottomless scrapers, the land plane and the drag scraper, which differ in the way in which grade is controlled.

The *land plane* is a bottomless scraper with a long frame extending both in front of and in back of the scraper, with wheels mounted at the ends of the frame. The blade on the land plane is mounted midway on the frame and is adjustable vertically so that the depth of cut and the amount of earth carried by the bucket can be regulated. Some

Figure 10.2. Ejector scrapers are a type of fixed-blade scraper used for moderate land grading and smoothing, operated singly (above) and in tandem (below).

planes are equipped with hydraulic controls so that the tractor operator can control the blade level from the tractor. Other planes are manually adjusted. When in use, the blade is set at a level that will maintain about one-third to one-half load in the bucket. If the blade is set too low, the soil in the bucket will become excessive, spilling around the ends and over the top of the bucket. If it is set too high, there will be insufficient soil to adequately fill the low areas. When the adjustment is properly made, the plane will automatically remove the high spots and fill in the depressions of a diameter equal to nearly half the machine length. Cuts of 6 to 9 cm or less can be made within the length of the machine.

Land planes are best suited for relatively large fields. They are manufactured in lengths up to about 27 m and with blade widths up to 4.5 m. From a smoothing standpoint, the longer the plane the better the smoothing job. From a maneuverability standpoint, the longer machines require a wider turning area, and thus will leave a wider strip around the boundaries of the field. Smaller fields will have greater proportions that cannot be properly smoothed. On fields of 8 ha or less and on narrow benches, smaller and more maneuverable planes are more desirable.

The two-wheel bottomless scraper, commonly known as a *drag scraper*, can be operated either manually by the tractor operator or by using laser-guided controls. Laser-controlled drag scrapers (Figure 10.3) and ejector scrapers (Section 10.6.2, Figure 10.2) have become the precision, land smoothing tools of choice. These machines are manufactured in a number of widths, up to 5.5 m, to serve various purposes. The drag scraper is well-suited for handling large volumes of earth over a short haul, while the ejector works for both short and long hauls. Manual smoothing can be done with the scrapers through visual control by the operator observing the grade to control the quality of finishing. Through the use of the hydraulic controls, the tractor operator can cut, drag, and unload as desired. When the drag scraper is used with operator control, it may be necessary to land plane the area to attain the required results. The laser-controlled drag scraper will do a more accurate job than a skilled operator using a manually operated drag scraper and/or land plane. Further, it relieves the operators of some of their machine control responsibilities, and if combined with available field

Figure 10.3. Laser-controlled drag scraper used for precision surface finishing. The battery-powered laser transmitter, with solar charger, is shown in the foreground and the receiving unit is shown mounted on the scraper.

surveying equipment can reduce or eliminate the need for traditional survey crews. Often manually operated drag scrapers are used before land planing to remove surface irregularities too minor to be taken care of economically with a carrier-type scraper.

10.6.3.2 Other levelers and floats. Farmers in their farm shops as well as various commercial companies have made excellent levelers and floats in many variations. Generally, the earth-moving principles are the same as for land planes, and the effectiveness is dependent on the length of the frame. Levelers and floats that can be pulled by the average farm tractor are more important in restoring the smoothness of a field after tillage than in removing the irregularities left by heavy earth-moving equipment.

10.7 FIELD OPERATING PROCEDURES

The land grading work must be planned and scheduled to assure satisfactory field conditions. Some of the factors that must be considered are timing, weather, and field condition.

- *Timing*—The field operations must fit into the cropping sequence. When appropriate, the grading should be scheduled so that the work can be carried out between the harvest of one crop and the planting of the next crop. The time available between crops will help determine the type of equipment to be used.
- *Weather*—While weather conditions cannot always be predicted, there is generally a time in each region when conditions are most favorable for grading work. If possible, the work should be planned for the most favorable season to avoid long shut-down periods. In particular, fieldwork should not be scheduled for periods of high rainfall, freezing temperatures, or other weather conditions that may cause excessive delays in earth moving or cause wind or water erosion.
- *Field conditions*—Some field conditions during land grading can have serious adverse effects on the quality of the work and crop production after it is done. Grading should not be done when the fields are excessively wet. Operating scrapers in wet soils is difficult and can cause compaction and other serious damage to the soil structure, which results in poor soil conditions for crop production. Grading of very dry soils should also be avoided. Cuts are difficult to make, fills become loose and powdery, and the result is poor quality work, higher cost of operating the equipment, and a dust hazard. Grading with excessive crop residues also should be avoided since it can result in poor compaction and excessive settling in deeper fill areas.

The quality of the land forming operation depends on the equipment used, condition of the field, and the skill of the operator. There are probably as many different ways of approaching the actual earth moving process as there are equipment operators. The earth-moving work should be carried out so that the grid stakes are not disturbed until the job is ready for the final smoothing operation. The farmer or contractor is normally given a map showing the work to be done. The information shown on the map depends on local custom and contractor preferences. In some cases it may be a map showing just the amount of cut or fill. A typical cut-and-fill map is shown in Figure 10.4. Numbers indicate the cut or fill in tenths of a meter. For example, C02 indicates that the cut is to be 0.2 m. If the grid point were marked F01, the fill would be 0.1 m. Some engineers make a detailed study of the contractor's map and prepare earthwork balance areas suggesting the direction and location that earth is to be moved. Most contractors or operators study the map and make their own decision on

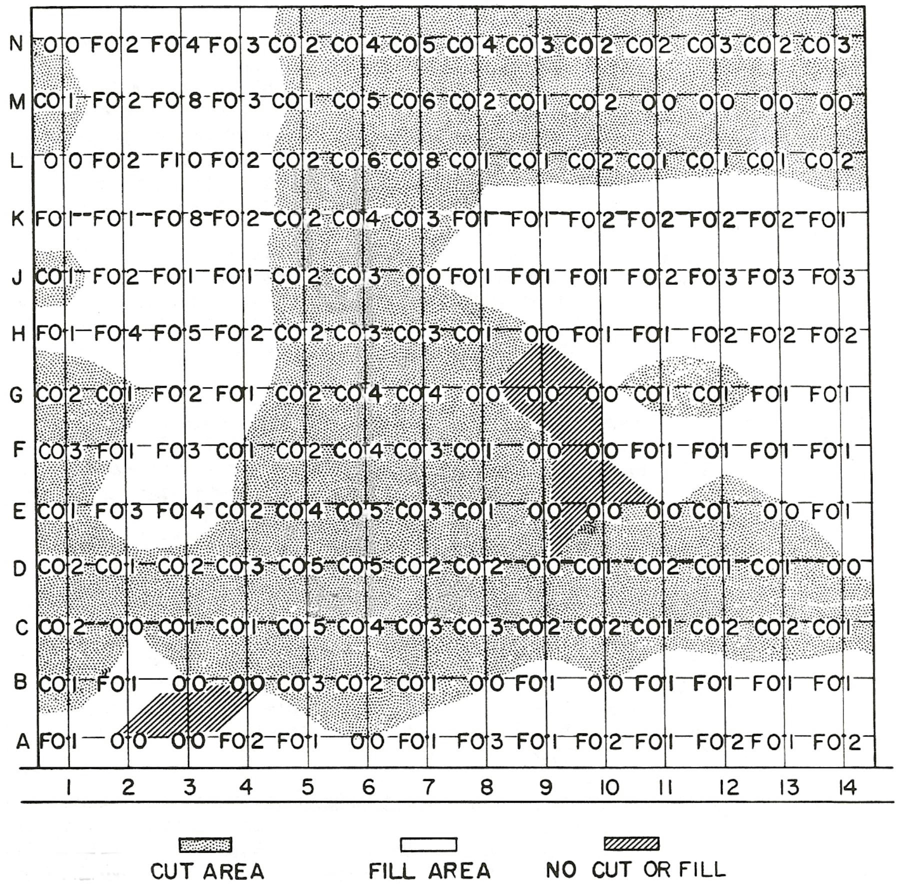

Figure 10.4. A typical cut-fill map used by the equipment operator. Cuts and fills are in tenths of a meter.

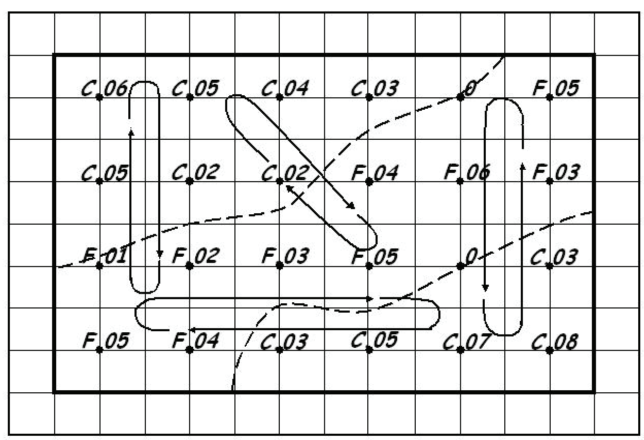

Figure 10.5. Field sketch of suggested haul lanes to be used by the land forming equipment operator to optimize the earthmoving process.

matching cut and fill areas. Figure 10.5 is an example of how the earth movement patterns might be visualized by the operator. On large, more complicated, jobs the haul patterns may be sketched out on the contractor's map. In some instances, the contractor may want a complete map showing original ground elevation, planned finished grade elevations, and the cut and fill figures. Other procedures include such things as indicating the cut with red figures and the fill with blue, or by cross-hatching the cut areas in red and the fill areas in blue.

10.7.1 Land Grading

Cutting and filling is normally done parallel to the grid stake rows. The procedure varies with operator preference and equipment. In some instances, when the scrapers are equipped with laser control equipment, field stakes are not used. The operator merely uses a cut-fill map of the area, some idea as to the most efficient method of going about the grading job, and uses the laser controls to provide the grade guidance needed. If the grade stakes are used, some operators cut and fill a strip the width of the scraper adjacent to the stake rows. The same procedure is followed for the opposite side of the lane along the next row of stakes. When these are brought approximately to grade, work is carried on in the intermediate area. When done without laser control, the grade between stake rows is carried visually across the lane. This process is continued until the entire field has been shaped. Another procedure is to make a cut along the stake row as deep as can be made on the first pass. The second strip is made just far enough over so that the tractor can straddle the strip that is left. The strip that was left is then removed as a third strip. This procedure is repeated across the cut area. Regardless of the procedure followed, the cuts and fills should be made in uniform layers. This reduces uneven settling of the field, facilitates carrying the proper grade from one stake row to the other, permits faster travel, and is easier on equipment. Normally the small area around each stake is left until the shaping is completed. If deep cuts are made leaving a large, high mound at the stake, it may be desirable to remove the stake, cut away the mound and replace the stake. Cut areas should be disked as soon as possible after the cuts are made to keep the cut surface from drying and becoming hard. This will make the preparations for the final smoothing easier.

Normally grades are checked with a permissible tolerance of ±60 mm. On level or flat grades it may be necessary to check within ±30 mm. In no case should reverse grades in the direction of irrigation be permitted. When the field construction has been approved, the stakes should be removed, the mounds and depressions at the grid stakes graded to the level of the adjacent surface, and the field disked or chiseled to prepare it for the final smoothing operation.

10.7.2 Land Smoothing

10.7.2.1 Land plane. Since the cut-and-fill operation by the heavy earth-moving equipment is normally carried out parallel to the rows of the grid stakes, it is generally desirable to carry out the first planing operations diagonally to the grid pattern. It is customary to land plane the field in three directions. The first two operations are in diagonal directions, perpendicular to each other, and the third is in the direction of irrigation. During the smoothing operations, considerable time is lost in making the turns at the field boundaries. Figure 10.6 shows how the first two diagonal planing operations can be carried out to cover the field with two passes of the plane in the minimum amount of time. This can reduce the time required by about 25% over planing the entire field in one diagonal direction and then repeating the operation at right angles to the first operation.

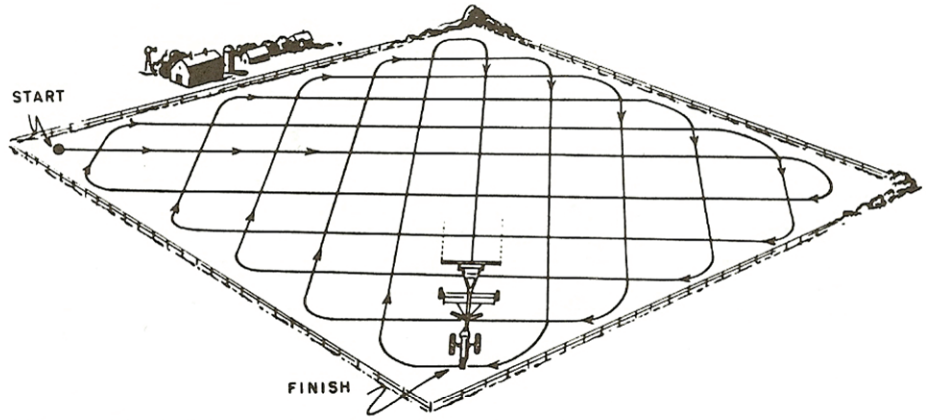

Figure 10.6. A method of performing two diagonal land planings in which distance traveled is minimized.

10.7.2.2 Drag and ejector scrapers. In recent years, the drag scraper or the ejector scraper with the moveable back of the scraper in the forward position, has become an excellent final smoothing machine, with laser control becoming state of the art after first being introduced in the mid-1970s as a tool to assist in land forming. Figure 10.3 shows a scraper and laser equipment in the field. The laser transmitter is mounted on a tripod, special stand, or trailer. It generates a thin laser beam that is rotated rapidly to form a virtual plane of light over the working area. The plane either can be level (for level basins) or sloping. The maximum range of the laser is about 300 m, but dust, wind, and heat can be limiting. However, these do not affect GPS-controlled systems, which have been adapted to land forming tools like the drag and ejector scrapers.

There are many personal preferences as to how the smoothing operation will be completed. If there are significant high and low areas, a typical approach is to use a field map as a guide to move soil from high to low areas. Once the field is close to on grade, or if there are no significant high and low areas to start with, the operator normally runs the scraper over the field in two or three directions with the last pass in the direction of irrigation. Fields smoothed in this way normally do not require further smoothing (e.g., land planing not required).

As noted earlier, land smoothing can be described statistically by the variability of the field elevations around the design slope. Field elevations are normally distributed; thus, the standard deviation of the field elevations from the design slope is an appropriate criterion for assessing smoothing adequacy. With well-trained operators and carefully adjusted equipment, standard deviations of the finished field elevations from the targeted field plane finished with laser-controlled scrapers range from about 12 to 15 mm on 4 to 16 ha fields (Dedrick, 1979; Dedrick et al., 1982). On level basins in the southwest, NRCS standards require 80% of a basin to be within $\pm$15 mm and 100% within ±30 mm. To meet the 80% criteria the standard deviation must be slightly less than 12 mm. Typically, standard deviations on “level” basins prior to laser-controlled smoothing ranged from 25 to 30 mm.

10.7.2.3 Water leveling. Water leveling for rice land is a method of field benching that was used extensively in the past, but in the United States it essentially has been replaced with laser-controlled scrapers. Rice is normally grown on soil having a restrictive layer with a permeability rate of about 0.5 mm or less per hour. If this restrictive layer is thick enough to support a tractor and scraper under a water-saturated condition, water leveling can be used. The equipment commonly used for water leveling is a bottomless scraper or a blade mounted on the back of a farm tractor. The general procedure is as follows:

- Smooth the field with a land plane to remove as many of the surface irregularities as possible.
- Locate and construct the permanent levees. Levees should be straightened by filling across the low areas.
- Flood as much area as can be leveled in one day to a depth that will cover the high point.
- Carry out the leveling work using the tractor-mounted blade or the bottomless scraper. Tractor movement produces water waves that assist the leveling operation. More than one tractor is often used to speed up the work and to create more wave action.
- Soil movement can be determined by water depth measurements.
- After the suspended soil material has settled and the water has become clear, the remaining water should be drained off.
- When the soil has dried sufficiently, the area between levees should be worked and smoothed with a land plane.

In some rice production areas, land forming is done to reduce the number of levees and to construct parallel levees. Final smoothing of the areas could be done with either water-leveling techniques or laser-controlled scrapers. Faulkner (1964) provides more detailed information on water leveling.

10.7.3 Maintenance

Land forming often requires a large investment of capital. Annual maintenance is an important part of the farmer's operation to obtain the proper return on this investment. Special treatment and annual maintenance is needed to bring land back to full production and keep the surface uniform. To improve soil condition after smoothing, tillage (e.g., plowing, disking, or chiseling) mixes the disturbed soil and loosens areas that have been compacted. In cold climates, leaving the soil surface in a roughened condition over winter will allow the frost action to break down clods and improve infiltration. If land forming has exposed infertile subsoils, soil testing is recommended. Reclamation practices might include a green manure crop the first year to add organic matter and/or applications of barnyard manure. These reclamation procedures may need to be supplemented with the application of fertilizer to meet crop requirements. Trace minerals, such as iron or zinc, are sometimes deficient in cut areas.

Following land shaping, irrigation, and farming operations, fill areas tend to settle and cut areas "fluff up" leaving the surface uneven. In some instances, final smoothing after major land forming may not be justified until the land has been irrigated. To provide an opportunity to refinish the area, farmers generally plant an annual crop the first year after land forming. The extent of the continuing maintenance procedures will depend on several factors such as the type of tillage equipment that is being used, time since major land forming processes were completed, type of crop to be grown, value of the crop to be grown, and the susceptibility of the crop to damage caused by soil surface irregularities and associated nonuniform water application.

Cultivation should be done carefully to help maintain precisely smoothed surfaces. Plowing should be done with a two-way plow. In some cases, sweeps or chisels are used to cut through the soil, raising and dropping the soil to provide a loosening effect.

10.8 COST AND CONTRACTING

The cost of earth work in land forming will vary with a number of factors: topography, field conditions, length of haul, total volume and volume of earth movement per unit area, type of equipment used, and the operator's skill. Competition among contractors and the need for off-season work often affects the cost.

In most areas the major earthwork is contracted based upon a volumetric basis. Final smoothing generally is contracted on a per unit area basis. In some instances, where the contractor does both the major land moving and finishing, the quoted price per unit volume includes final smoothing.

Most contracting is done on a verbal agreement between the contractor and the farmer or landowner. This sometimes leads to misunderstandings. The following items are suggested as some of the things that should be covered by a written agreement:

- field location and description of site conditions;
- basis for the construction such as the contractor's work map, special construction not shown on the map, allowance for settlement in heavy fill areas, cut-to-fill ratio, etc.;
- facilities, materials, and assistance which the farmer will provide to the contractor;
- who will do the smoothing and when it is to be done, if the final smoothing is to be done as a separate job;
- completion date with provisions for extension if factors beyond the contractor's control delay the progress of the work;
- basis for payment (if based on volume, the method to be used for determining the volume and who is going to do the computation should be stated; agreement should be made on how the field will be checked for completion);
- liability insurance;
- responsibility for locating and protecting buried utilities;
- final clean-up of rubbish, excess materials and equipment, broken equipment, etc; and
- pay schedule.

10.9 SAFETY

All equipment must have the required safety devices and should be operated in a reasonable and safe manner. Safety shields must be in place and securely fastened. Special precautions should be taken when operating equipment around electric power lines, buried utilities, and communication lines. Buried utilities and communication lines have been damaged and lives lost during land grading operations. The general location of the buried utility should be indicated on the contractor's map. Most utility companies will, on request, stake the exact location of their utility line and indicate the depth of the cover over the line. While some governmental agencies serve written notice to the farmer that he is responsible for notifying the utility company of the work to be done on his farm, all parties involved in the land forming must be safety conscious.

Dust associated with land forming can be a serious problem, especially during and after the final smoothing operation. Dust affects nearby residents, creates hazardous conditions on nearby roads, and can damage crops on adjacent farmland. As noted earlier, land forming on dry soils should be avoided, both from a quality of job standpoint (i.e., loose soil is difficult to smooth) and from a dust (health and safety) standpoint. In some instances, temporary irrigation facilities, such as portable sprinklers, may need to be used to provide better working conditions. If soil moisture is adequate, working the field with small chisels or a spring-tooth harrow may provide sufficient surface roughening to control blowing dust. The finished field should be irrigated and planted as soon as possible. If the planting of the next crop is to be delayed for any length of time, it may be advisable to plant a cover crop to provide adequate protection from wind erosion.

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